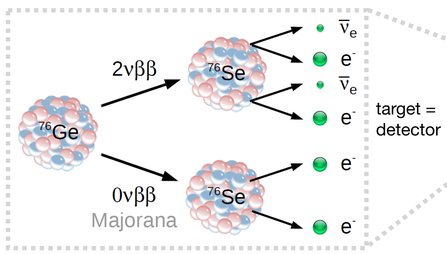
LEGEND ^{76}Ge Detectors:
Production, Characterization, Performance

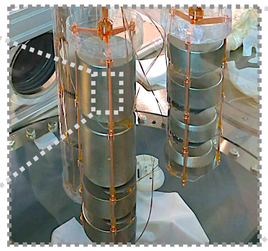
I. Abt, A. Alexander, P. Barton, V. Biancacci, B. Bos, R. Brugnera, M. Busch, T. Caldwell, C.-A. Christofferson, M. Clark, T. Comellato, J. Detwiler, F. Edzards, A. Engelhardt, A. Garfagnini, C. Gooch, J. Gruszko, I. Guinn, K. Gusev, L. Hauertmann, M. Hult, Y. Kermaidic, B. Lehnert, X. Liu, G. Lutter, G. Marissens, R. Martin, T. Mathew, S. Mertens, G. Othman, L. Pertoldi, A. Poon, D. Radford, A. Reine, S. Schoenert, O. Schulz, J. Thompson, K. Warnello, J.F. Wilkerson, C. Wiseman, A. Zschocke
for the LEGEND Collaboration

LEGEND (arXiv:1709.01980)

Search for Double Beta Decay in ^{76}Ge

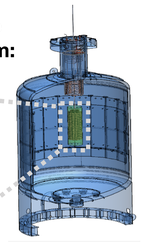


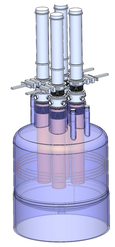
target = detector



detectors in array submerged into liquid argon

2-stage program:



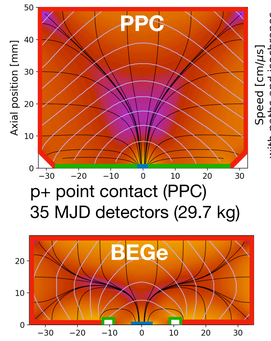


	LEGEND-200	LEGEND-1000
Start:	2021	tbc (2026?)
Location:	LNGS	tbc (SNOLAB?)
$0\nu\beta\beta$ $T_{1/2}$:	$>10^{27}$ yr	$>10^{28}$ yr
background index cts / (FWMH t yr)	<0.6	<0.03

Double beta decay in ^{76}Ge (Q = 2039 keV)
SM allowed $2\nu\beta\beta$: $T_{1/2} = 2.0\times10^{21}$ yr (continuous) [1]
Beyond SM $0\nu\beta\beta$: $T_{1/2} > 0.9\times10^{26}$ yr (peak search) [2]

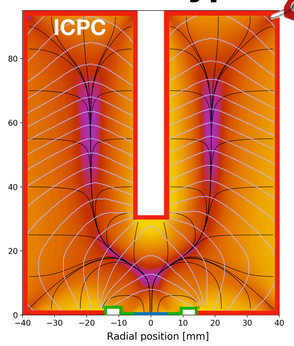
Target = detector (HPGe)
^{76}Ge enriched from 7.6% to 88%
Semiconductor with FADC readout

LEGEND-200 Detectors Types



p+ point contact (PPC)
35 MJD detectors (29.7 kg)

Broad Energy Germanium (BEGe)
28 GERDA detectors (19.0 kg)

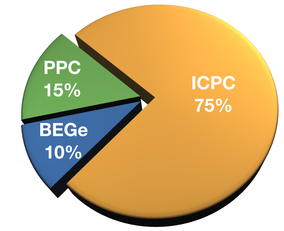


Inverted coaxial point contact (ICPC)
≈80 new detectors (≈150 kg)

NEW
5 ICPC detectors already deployed in GERDA Phase II+

Surfaces:
- n+ electrode
- p+ electrode
- passivation

Advantages new ICPC detectors:
- Significantly larger (x2-4)
- Fewer channels, less background
- Better surface-volume-ratio (30-40%)
- Similar ΔE, PSD performance



Detector composition L-200

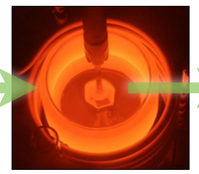
23 ICPC detectors already produced

Production & Logistics

Two manufactures: MIRON, ORTEC (+R&D with PhDs Co.) in EU and US


enrichment: $^{enr}GeO_2$


zone refinement: 6N ^{enr}Ge


crystal pulling


ingot

1-2 detector (1.5-3.5 kg)

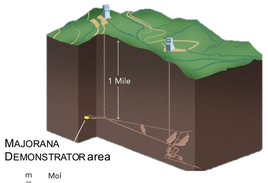
Reduce cosmic activation: Characterization close to production, shielded transport container

logistics between US and Europe

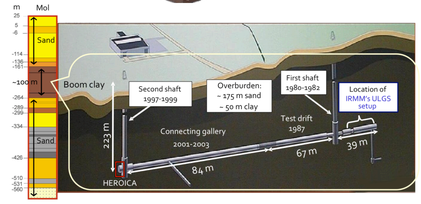

shielding for transport: ^{enr}Ge (30 kg) in shipping container (26 t)

Detector Characterization

- Two characterization sites in Europe and US
- Underground to reduce cosmic activation



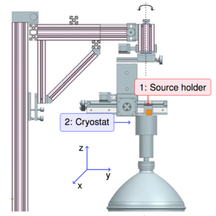
SURF underground lab (1480 m) in Lead, South Dakota, USA



HADES underground lab (225 m) in Mol, Belgium

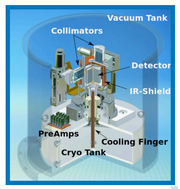
Standard campaign for all new detectors
- Test performance requirements (Depletion < 4000 V, energy resolution ΔE)
- Determine dead layer & active volume (PSD parameters may differ between vacuum and LAr)
- Test new DAQ systems and analysis software suite


Static measurements:
(^{232}Th, ^{60}Co, ^{136}Ba)

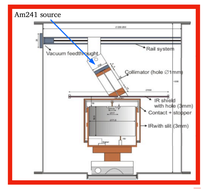


Surface scans:
(collimated ^{241}Am)

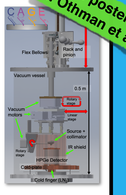
Special campaigns for prototype detectors
- Understanding surface events
- Develop pulse-shape discrimination



GALATEA @MPP
α, β, γ scans



TUBE @TUM
α scans


CAGE @UW
α, β, γ scans

see poster G. Othman et al.

More special setups in LEGEND institutions:
- TUM: LAr cryostat with ^{42}K spike
- Queen's: n+ surface investigations
- UNC: fast surface scanner
- LBNL: flexible β, low-E γ sources

Performance & Background Rejection

- BEGe and ICPC detectors successfully operated in LAr with low background (GERDA Phase II+)
- PPC detectors not yet tested in LAr. Large thin passivated surface sensitive to α, β background
- MJD electronics and GERDA shielding strategy will improve on past performance of PPC and BEGe detectors

	PPC	BEGe	ICPC
<M> [kg]	0.85	0.67	2.0*
<ΔE> [keV] FWHM @2039 keV	2.5	2.7	2.9#
background index [cts / (keV t yr)]	1.6	0.6	<2.6#

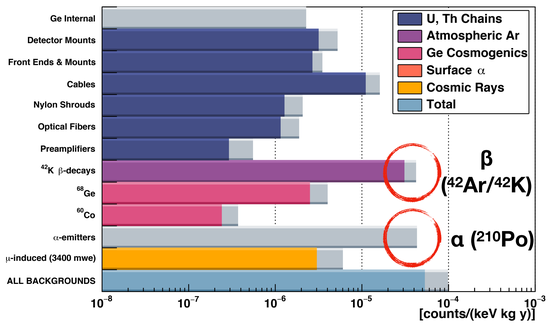
PPC's as operated in MJD vacuum cryostat [3]

BEGe's as operated in GERDA LAr cryostat [2]

(*) of 23 ICPC detectors at hand

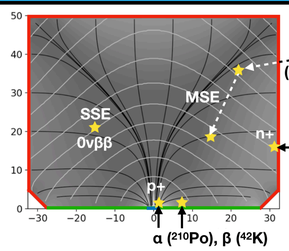
(#) of 5 ICPC detectors operated in GERDA Phase II+ [4]

LEGEND-200 background prediction after cuts



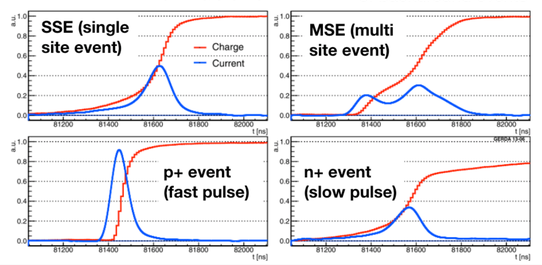
- LEGEND-200: α and β events are largest background components (α bkg dominated by PPCs)
- LEGEND-1000: ^{42}Ar / ^{42}K background mitigated by underground argon, α-background reduced in ICPCs

Background event topologies

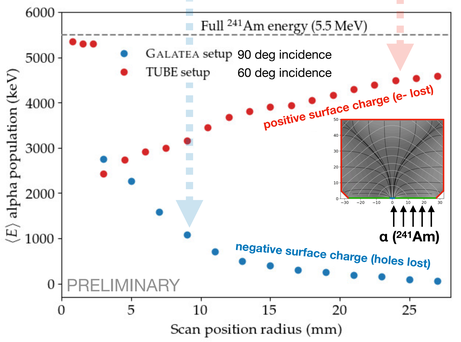


Surfaces:
- n+ electrode (≈1 mm)
- p+ electrode (≈0.3 µm)
- passivation (≈0.1 µm)

Pulse shape discrimination of backaround events



- Passivated surface scan with ^{241}Am α-source
- Response strongly dependent on surface charge
- Loss of signal from different charge carriers (e^- or holes)
  - Strong energy degradation
  - Pulse-shape discrimination possible



[1] GERDA Collab., Eur. Phys. J. C 75, 416 (2015) [link]
[2] GERDA Collab., *Science* 365, 1445 (2019) [link]
[3] Majorana Collab., PRL 120, 132502 (2018) [link]
[4] C. Wiesinger, TAUP 2019 [link]

legend-exp.org

We appreciate the support of our sponsors:
German Federal Ministry for Education and Research (BMBF)
German Research Foundation (DFG), Excellence Cluster Universe
German Max Planck Society (MPG)
U.S. National Science Foundation, Nuclear Physics (NSF)
U.S. Department of Energy, Office of Nuclear Physics (DOE-NP)
U.S. Department of Energy, Through the LANL, ORNL & LBNL LDRD programs (LDRD)
Italian Instituto Nazionale di Fisica Nucleare (INFN)
Swiss National Science Foundation (SNF)
Polish National Science Centre (NCN)
Foundation for Polish Science
Russian Foundation for Basic Research (RFBR)
Research Council of Canada, Natural Sciences and Engineering
Canada Foundation for Innovation, John R. Evans Leaders Fund
European Research Council
Science and Technology Facilities Council, part of UK Research and Innovation
We thank our hosts and colleagues at LNGS and SURF
We thank the ORNL Leadership Computing Facility and the LBNL NERSC Center

NEUTRINO 2020